Use of the double dispersion relation in QCD sum rules with external fields

Hungchong Kim [*]

Department of Physics, Tokyo Institute of Technology, Tokyo 152-8551, Japan

Abstract

In QCD sum rules with external fields, the double dispersion relation is often used to represent the correlation function. In this work, we point out that the double spectral density, when it is determined by successive applications of the Borel transformation, contains the spurious terms which should be kept in the subtraction terms in the double dispersion relation. They are zero under the Borel transformation but, if the dispersion integral is restricted with QCD duality, they contribute to the continuum. For the simple case with zero external momentum, it is shown that subtracting out the spurious terms is equivalent to the QCD sum rules represented by the single dispersion relation.

PACS: 12.38.Lg; 11.55.Hx

Typeset using REVTEX

---

[*]E-mail : hckim@th.phys.titech.ac.jp, JSPS fellow

The QCD sum rule [1] is widely used in studying hadronic properties based on QCD [2]. In this framework, a correlation function is introduced as a bridge between the hadronic and QCD representations. In the QCD side, the perturbative part and the power corrections are calculated in the deep space-like region ($q^2 = -\infty$) using the operator product expansion (OPE), which is then used to extract the hadronic parameter of concern by matching with the corresponding hadronic representation.

In matching the two representations, it is crucial to represent the correlator using a dispersion relation. Usually in the nucleon mass sum rule as an example, the single-variable dispersion relation is used. With this, the QCD correlator calculated in the deep space-like region can be related to its imaginary part defined in the time-like region, which is then compared with the corresponding hadronic spectral density to extract the hadronic parameter of concern. The hadronic spectral density contains contributions from higher resonances as well as the pole from the low-lying resonance of concern. To subtract out the continuum, QCD duality is invoked above a certain threshold where the continuum contribution is equated to the perturbative part of QCD. This duality restricts the dispersion integral below the continuum threshold in the matching. Therefore, the predictive power of QCD sum rules relies heavily on the duality assumption. Indeed, in the quantum mechanical examples, the parton-hadron duality works well for two-point correlation functions [3].

Often, within the QCD sum rule framework, a correlation function with an external field is considered to calculate for examples pion-nucleon couplings [4–6], nucleon magnetic moment [7]. In such a case, as the two baryonic lines propagate through the correlator at the tree level, the double-variable dispersion relation [8] can be invoked to represent the correlation function. Namely,

$$\Pi(p_1^2, p_2^2) = \int_0^\infty ds_1 \int_0^\infty ds_2 \frac{\rho(s_1, s_2)}{(s_1 - p_1^2)(s_2 - p_2^2)} + \text{subtractions} . \tag{1}$$

The subtraction terms serve to eliminate infinities coming from the integral. They are usually polynomials in p_1^2 or p_2^2, which vanish under the Borel transformations. Thus, the subtraction terms should not contribute to the sum rules. As before, QCD duality is imposed to the correlator, which restricts again the dispersion integral below a certain threshold for both integration variables, s_1 and s_2.

In general, the double spectral density $\rho(s_1, s_2)$ in the double dispersion relation of Eq. (1) is obtained formally by matching the correlation function with its corresponding OPE Π^{ope} [1] calculated in the deep Euclidean region using QCD degrees of freedom. That is,

$$\Pi(p_1^2, p_2^2) = \Pi^{\text{ope}}(p_1^2, p_2^2) + \text{subtractions} . \tag{2}$$

The LHS contains the spectral density in the integrals as given in Eq. (1). To solve for the spectral density $\rho(s_1, s_2)$ from this formal equation, successive Borel transformations are needed to apply [9,10] on both side. This will eliminate the unnecessary subtraction terms. In doing so, the integrals are disappeared, reducing to a simple equation for the spectral density in terms of a given OPE. However, such a chosen spectral density, when it is put

---

[1]In this work, we focus mainly on the OPE terms which contribute to the continuum.

back to the double dispersion integral Eq. (1), can reproduce the original OPE up to some *subtraction terms.* Of course, the additional subtraction terms do not matter if a sum rule are constructed using precisely Eq. (1). But in fact, in constructing continuum contribution, the duality argument is imposed, which further restricts the dispersion integral. If this restricted form of the dispersion integral is used, the subtraction terms do not vanish even after the Borel transformations. In this work, we point out with some explicit examples that QCD sum rules using the double dispersion relation contain these spurious contributions.

To proceed, we first demonstrate how the spectral density in the double dispersion relation is usually determined [9,10]. The Borel transformation $\mathcal{B}(M^2, Q^2)$ is defined as

$$\mathcal{B}(M^2, Q^2)f(Q^2) = \lim_{Q^2, n \to \infty, \ Q^2/n = M^2} \frac{(Q^2)^{n+1}}{n!} \left(-\frac{d}{dQ^2} \right)^n f(Q^2) \ . \tag{3}$$

With this definition, the Borel transformation converts the Q^2 dependence of the function f into the Borel mass dependence, M^2. In doing so, polynomials in Q^2 vanish. By applying the double Borel transformations on Eq. (1), we obtain,

$$\mathcal{B}(M_2^2, -p_2^2)\mathcal{B}(M_1^2, -p_1^2)\Pi(p_1^2, p_2^2) = \int_0^\infty ds_1 \int_0^\infty ds_2 \rho(s_1, s_2) \ e^{-s_1/M_1^2 - s_2/M_2^2} \ , \tag{4}$$

where we have used the formula,

$$\mathcal{B}(M^2, Q^2) \left(\frac{1}{Q^2 + \mu^2} \right)^n = \frac{1}{\Gamma(n)(M^2)^{n-1}} e^{-\mu^2/M^2} \ . \tag{5}$$

To eliminate the integral, we further perform additional double Borel transformations and obtain,

$$\mathcal{B}(\tau_2^2, \frac{1}{M_2^2})\mathcal{B}(\tau_1^2, \frac{1}{M_1^2})\mathcal{B}(M_2^2, -p_2^2)\mathcal{B}(M_1^2, -p_1^2)\Pi(p_1^2, p_2^2) = \rho(\frac{1}{\tau_1^2}, \frac{1}{\tau_2^2}) \ , \tag{6}$$

where another formula for the Borel transformation,

$$\mathcal{B}(M^2, Q^2)e^{-a^2 Q^2} = M^2 \delta(a^2 M^2 - 1) \ , \tag{7}$$

has been used. Note in this derivation, $s_1 = 1/\tau_1^2 \geq 0$ and $s_2 = 1/\tau_2^2 \geq 0$, thus restricting the spectral density only in the region $s_1, s_2 \geq 0$.

The OPE spectral density can be obtained by applying this operation on a given OPE. Note also that the integral interval should include the point provided by the delta functions. If the interval does not include the point, $s_1 = 1/\tau_1^2$ or $s_2 = 1/\tau_2^2$, then Eq. (6) is not conclusive. We stress that the spectral density determined via Eq. (6) is correct within this context, obtained by successive applications of Borel transformation on the dispersion integral limited from zero to infinity. The subtraction terms, as they vanish under the Borel transformations, can be chosen freely as we like.

In practice, however, QCD sum rules require a certain assumption for high energy part of the correlator, QCD duality. With this assumption, the dispersion integral is restricted below the continuum threshold S_0, and the Borel-transformed sum rule becomes,

$$\int_0^{S_0} ds_1 \int_0^{S_0} ds_2 \rho^{\text{ope}}(s_1, s_2) \ e^{-s_1/M_1^2 - s_2/M_2^2} = \int_0^{S_0} ds_1 \int_0^{S_0} ds_2 \rho^{\text{phen}}(s_1, s_2) \ e^{-s_1/M_1^2 - s_2/M_2^2} \tag{8}$$

$\rho^{\mathrm{phen}}(s_1, s_2)$ is obtained from hadronic representation of the correlator while $\rho^{\mathrm{ope}}(s_1, s_2)$ is obtained via Eq. (6) for a given OPE. The LHS restricted below the continuum threshold S_0 can be calculated directly using the spectral density obtained from Eq.(6). Another equivalent method which is more useful for our discussion is to calculate the LHS via

$$\mathcal{B}(M_2^2, -p_2^2)\mathcal{B}(M_1^2, -p_1^2)\left[\Pi^{\mathrm{ope}}(p_1^2, p_2^2) - \int_{S_0}^{\infty} ds_1 \int_{S_0}^{\infty} ds_2 \frac{\rho^{\mathrm{ope}}(s_1, s_2)}{(s_1 - p_1^2)(s_2 - p_2^2)}\right] . \qquad (9)$$

Note that the continuum is subtracted out from the OPE using the duality argument. Integral intervals like $\int_{S_0}^{\infty} ds_1 \int_0^{S_0} ds_2$ or $\int_0^{S_0} ds_1 \int_{S_0}^{\infty} ds_2$ do not contribute because, as we will see, the spectral density is of the form $\sim \delta(s_1 - s_2)$ at least in our examples that will be considered in this work. The integral in the second term is bounded below by S_0. As we have stressed above, in determining the spectral density via Eq. (6), it is important that the dispersion integral is limited from zero to infinity. Since the second integral is bounded below by S_0 due to the duality argument, it is not clear if the subtraction terms as written in Eq. (1) do not participate in the sum rule. This is our main question to be addressed in this work.

Let us proceed how our question is realized in QCD sum rules with external fields. To do so, we consider as an example the two-point correlation function with a pion,

$$\Pi(q, p_\pi) = i \int d^4x e^{iq \cdot x} \langle 0|T[J_N(x)\bar{J}_N(0)]|\pi(p_\pi)\rangle , \qquad (10)$$

where J_N is the nucleon interpolating field proposed by Ioffe [11]. To be specific, let us take a typical OPE from this correlation function,

$$\Pi_1^{\mathrm{ope}} = \int_0^1 du \, \varphi_p(u) \, ln[-(q - up_\pi)^2] \sim \int_0^1 du \, \varphi_p(u) \, ln[-up_2^2 - (1 - u)p_1^2] . \qquad (11)$$

Here $p_1^2 = q^2$ and $p_2^2 = (q - p_\pi)^2$. We have taken the limit $p_\pi^2 = m_\pi^2 = 0$ as is usually done in the light-cone QCD sum rules [12]. Note, Eq. (11) contains terms polynomials in p_1^2 or p_2^2 but we did not specify these subtraction terms explicitly. For the twist-3 pion wave function, we take its asymptotic form, $\varphi_p(u) = 1$ [12]. With higher conformal spin operators, the wave function takes more complicate form but our claims in this work are still valid even with more general wave functions. We will discuss this point later.

To obtain the double spectral density, we take the operation as given in Eq. (6). For Π_1^{ope}, we straightforwardly obtain

$$\rho_1^{\mathrm{ope}}(s_1, s_2) = -s_1\delta(s_1 - s_2) . \qquad (12)$$

Note, the spectral density is defined only in the region $s_1, s_2 \geq 0$. Therefore, the spectral density should be understood as being multiplied by the step function, $\theta(s_1)\theta(s_2)$. To include entire region of $\rho(s_1, s_2) \neq 0$, the lower boundary of the dispersive integral should be understood as 0^-, infinitesimal but negative value. This subtlety does not matter in this example but is important in later examples.

Normally, ρ_1^{ope} is simply used in QCD sum rules Eq. (9) without justifying its use carefully. To see a problem with this spectral density, we put this expression into Eq. (1) and perform the integrations using the Feynman parametrization,

4

$$\int_0^\infty ds_1 \int_0^\infty ds_2 \frac{\rho_1^{\mathrm{ope}}(s_1, s_2)}{(s_1 - p_1^2)(s_2 - p_2^2)} = \int_0^1 du \int_0^\infty ds \frac{-s}{[s - up_2^2 - (1-u)p_1^2]^2}$$

$$= -\int_0^1 du \left[\frac{-up_2^2 - (1-u)p_1^2}{s - up_2^2 - (1-u)p_1^2} \bigg|_0^\infty + ln[s - up_2^2 - (1-u)p_1^2] \bigg|_0^\infty \right] . \tag{13}$$

The second term in the last line is the anticipated logarithmic term matching the OPE of Eq. (11). In other words, the second term is enough to reproduce the Borel-transformed OPE of Eq. (11). This means that the first term is spurious and it vanishes under Borel transformations with respect to the variables, $-p_1^2$ and $-p_2^2$. Therefore, it is a part of subtraction terms and should not contribute to the QCD sum rule. That is, we have to subtract out this term using our freedom to choose any subtraction term. Of course, this subtraction by hand is not necessary if the sum rule is used in the context of Eq. (4). However, in practice, the sum rule is used in the context of Eq. (9) invoking QCD duality. The continuum part from this subtraction term,

$$-\int_0^1 du \frac{-up_2^2 - (1-u)p_1^2}{s - up_2^2 - (1-u)p_1^2} \bigg|_{S_0}^\infty , \tag{14}$$

becomes, under the double Borel transformation,

$$S_0 M^2 e^{-S_0/M^2} \quad \text{where} \quad \frac{1}{M^2} = \frac{1}{M_1^2} + \frac{1}{M_2^2} . \tag{15}$$

This nonzero continuum is spurious as it originated from the subtraction term. A prescription for including the continuum presented in Ref. [13] can be obtained when this spurious continuum is kept and it is often used in the light-cone QCD sum rules [14]. However, keeping this term while neglecting the OPE subtraction terms in Eq. (11) is inconsistent.

We now consider a slightly different OPE from Eq. (10),

$$\Pi_2^{\mathrm{ope}} = \int_0^1 du \varphi_p(u) \frac{1}{-up_2^2 - (1-u)p_1^2} \tag{16}$$

Again we take the asymptotic form for the pion wave function $\varphi_p(u) = 1$ for simplicity. Note, when the external momentum is zero, we have $\Pi_2^{\mathrm{ope}} = -1/p^2$ $(p_1^2 = p_2^2 = p^2)$. It is clear that this OPE should not contribute to the continuum. Even if the sum rule is constructed with nonzero external momentum, this aspect should be recovered whenever we take the external momentum zero. Under the successive applications of the Borel transformation, it is straightforward to obtain the corresponding spectral density,

$$\rho_2^{\mathrm{ope}}(s_1, s_2) = \delta(s_1 - s_2)\theta(s_1) . \tag{17}$$

Here we put the step function explicitly because the subtlety associated with the lower boundary affects the discussion. Using this spectral density, Eq. (1) becomes

$$\int_0^1 du \int_{0^-}^\infty ds \frac{\theta(s)}{[s - up_2^2 - (1-u)p_1^2]^2} . \tag{18}$$

Note, we have 0^- for the lower limit of the integral in order to ensure that the integration includes entire region of $\rho_2(s_1, s_2) \neq 0$. Integration by part leads to

$$\int_0^1 du \int_{0^-}^\infty ds \frac{\delta(s)}{s - up_2^2 - (1-u)p_1^2} - \int_0^1 du \frac{\theta(s)}{s - up_2^2 - (1-u)p_1^2}\Bigg|_{0^-}^\infty . \tag{19}$$

Here the first term yields the anticipated OPE of Eq. (16) and the second term, as the lower limit lies just below the zero, is zero. Note also that this separation becomes possible because the subtlety with the lower boundary. If there were no subtlety with the lower boundary, then we would not have the first term containing the delta function. If this were true, then in the limit of zero external momentum, Eq.(16) can not be equal to Eq.(19), which does not make sense.

It is the second term that should be a part of the subtraction terms. Of course, this separation does not have any mathematical significance. It is however important physically because this separation enables us to identify where the spurious contribution to the sum rule comes from. That is, the second term, when the lower limit changes to S_0, survives under the Borel transformations and contributes to the continuum. Once again, we have identified a spurious subtraction which contributes to the sum rule.

Up to now, from the two simple examples, we have shown that QCD sum rules invoking the double dispersion relation contain the spurious terms originated from the subtraction terms. They contribute to the sum rule when QCD duality is imposed. This is a general statement as long as QCD sum rules are constructed using Eqs. (8),(9) while the spectral density is determined via Eq. (6). In general, for the correlator of Eq. (10) as an example, the OPE contains complicate functions like the pion wave functions. The general twist-3 pion wave function can be written [12],

$$\varphi_p(u) = \sum_k a_k u^k . \tag{20}$$

Using this general form, Π_2^{ope} under the double Borel transformations becomes

$$\varphi_p(u_0) M^2 \tag{21}$$

where $u_0 = M_1^2/(M_1^2 + M_2^2)$ and $M^2 = M_1^2 M_2^2/(M_1^2 + M_2^2)$. Under additional Borel transformations, the spectral density can be shown to be proportional to derivatives of $\delta(s_1 - s_2)$. The dispersion integral of Eq. (1) can be performed by integrations by part but, in doing so, the boundary terms become parts of the subtraction terms and produce the spurious continuum contributions when the sum rule is combined with QCD duality. In general, it is difficult to eliminate these spurious terms systematically. This is a generic problem in the sum rules using the double dispersion relation combined with QCD duality.

Now, let us consider a simple case with the zero external momentum. As a specific example, we consider the two-point correlation function with a pion with the vanishing pion momentum (the soft-pion limit) or the same correlation function with one pion momentum taken out as an overall factor but in the rest with $p_\pi^\mu = 0$ [5,6,15] (beyond the soft-pion limit). Even in this case, the double dispersion relation is proposed as a correct representation of the correlator [8]. The double dispersion relation might be useful in treating phenomenological side properly but the spurious terms still persist.

The double spectral density in this case takes the form

$$\rho(s_1, s_2) = \rho(s_1)\delta(s_1 - s_2) . \tag{22}$$

Since the two correlator momenta are equal in this case, the delta function appears as a part of the spectral density. The double dispersion relation Eq. (1) reduces to

$$\Pi(p^2) = \int_0^\infty ds \frac{\rho(s)}{(s-p^2)^2} + \text{subtractions} .\tag{23}$$

Unlike to the single dispersion relation, the correlation function contains square of $s - p^2$ in the denominator. The spectral density $\rho(s)$ is obtained by

$$\mathcal{B}(\tau^2, \frac{1}{M^2})\mathcal{B}(M^2, -p^2)\Pi(p^2) = \frac{\partial \rho(s)}{\partial s}\bigg|_{s=1/\tau^2}\tag{24}$$

Thus, we can determine the derivative of the spectral density for a given OPE. The OPE corresponding to Eq. (11) is $ln(-p^2)$. We do not need to worry about the pion wave function $\varphi_p(u)$ since its overall normalization, which is fixed to the unity, participates in the case.

Substituting $ln(-p^2)$ into Eq. (24), we obtain

$$\frac{\partial \rho(s)}{\partial s}\bigg|_{s=1/\tau^2} = -1 \implies \rho(s) = -s + \text{constant} .\tag{25}$$

The constant term, when put into the dispersion integral, yields the term $1/p^2$. To be consistent with the logarithmic behavior of the OPE, the constant should be zero. The rest of the spectral density leads to the dispersion integral,

$$\int_0^\infty ds \frac{-s}{(s-p^2)^2} = \frac{p^2}{s-p^2}\bigg|_0^\infty - ln(s-p^2)\bigg|_0^\infty .\tag{26}$$

The second term in the RHS is what we have anticipated. This is what one would have obtained if the single dispersion relation is used. Again, this is enough to reproduce the Borel-transformed OPE of $ln(-p^2)$. But, as before, the first term in the RHS is spurious. This term is zero under the Borel transformation but the continuum gives nonzero contribution to the sum rule. Note that the first term can be separated as

$$\frac{p^2}{s-p^2}\bigg|_0^\infty = \frac{p^2}{s-p^2}\bigg|_0^{S_0} + \frac{p^2}{s-p^2}\bigg|_{S_0}^\infty .\tag{27}$$

What is interesting is that the contribution from the upper limit in the first term cancels the one from the lower limit in the second term. These two terms coming from the continuum threshold survive separately under the Borel transform though their sum is still zero. If the spectral density of Eq. (25) is simply used in the sum rule of Eq. (8), then the lower limit from the second term contributes to the continuum while the upper limit from the first term does not participate to the sum rule Eq. (8). Once again, the spurious nature of this continuum is obvious.

Another way to support our claim is to consider the correlator Eq. (10) in the soft-pion limit. According to the soft-pion theorem, the correlator becomes the commutator with the axial charge Q_5,

$$\Pi(q, p_\pi = 0) \sim i \int d^4x e^{iq \cdot x} \langle 0| \left[Q_5, T[J_N(x)\bar{J}_N(0)]\right] |0\rangle .\tag{28}$$

7

The commutator, if it is readily evaluated using the commutation relation for the quark fields, becomes the anticommutator,

$$\Pi(q, p_\pi = 0) \sim \left\{ \gamma_5, \ i \int d^4 x e^{iq \cdot x} \langle 0 | T \left[J_N(x) \bar{J}_N(0) \right] | 0 \rangle \right\} . \qquad (29)$$

It means, in the soft-pion limit, Eq. (10) is equivalent to the nucleon chiral-odd sum rule, which should be represented by the single dispersion relation in the construction of its sum rule. Note, in deriving this, we have used only the soft-pion theorem and the commutation relation for the quark fields. Therefore, this is an operator identity that has to be satisfied always. But if one starts from the double dispersion relation and takes the soft-pion limit afterward, then Eq. (29) is not satisfied exactly by the presence of the spurious term like $\frac{p^2}{s-p^2}\big|_0^\infty$ in Eq. (26).

Indeed, the spurious terms lead to different continuum factors as appeared in Ref. [15,16]. A similar discussion can be found in Ref. [17] where we simply point out a pole at the continuum threshold, not clarifying its spurious nature. It is currently under-debate whether or not keep the terms in question in QCD sum rules with external fields [18]. But it is now clear from our discussion that they are spurious. Anyway, once the spurious subtractions are eliminated, then what is left is the same sum rule that we would have obtained via the single dispersion relation. Our argument can be generally applied to other OPE contributing to the continuum and it can be shown that subtracting the spurious continuum leads to the sum rule invoking the single dispersion relation. Normally, the continuum contribution is denoted by the factors, $E_n(x \equiv S_0/M^2) = 1 - (1 + x + \cdots + x^n/n!)e^{-x}$. Subtracting the spurious continuum replaces the continuum factor, $E_n(x) \to E_{n-1}(x)$ for $n \geq 1$. The changes due to this spurious term are sometime huge as discussed in Ref. [6]. In Ref. [6], figure 1 shows for the sum rules with $i\gamma_5 p_\mu \gamma^\mu$ structure how this spurious continuum changes the Borel curve of πNN coupling. There, the Borel curve with the spurious continuum varies within the range 11.5 - 11.2. But without this spurious continuum, the variation scale becomes 15 - 30, clearly showing huge effects from the spurious terms. The πNN coupling extracted from this Borel curve will be quite different from what we know experimentally. As discussed in Ref. [6], however, this only says that the Dirac structure $i\gamma_5 p_\mu \gamma^\mu$ is not adequate for calculating the coupling. Instead, $i\gamma_5$ or $\gamma_5 \sigma_{\mu\nu} q^\mu p^\nu$ Dirac structure is more useful to calculate the coupling [5]. Nevertheless, from this consideration, we see that the spurious continuum sometime becomes substantial and thus should be treated carefully.

In summary, we have pointed out in this work that QCD sum rules with external fields employing a double dispersion relation can contain the spurious continuum originated from the subtraction terms. This spurious term appears because the spectral density obtained via successive applications of the Borel transformation is not compatible with QCD duality. The spurious term should be subtracted out using the freedom for subtraction terms in QCD sum rules. In the case with the zero external momentum, subtracting the spurious term is equivalent to the sum rules invoking the single dispersion relation. Of course, our finding only affects continuum contributions but in some cases this modification leads to significant corrections to QCD sum rule results as is presented in Ref. [6].

ACKNOWLEDGMENTS

REFERENCES

[1] M.A. Shifman, A.I. Vainshtein, and V.I. Zakharov, Nucl. Phys. **B 147**,385,448 (1979).

[2] L.J. Reinders, H. Rubinstein and S. Yazaki, Phys. Rep. **127**, 1 (1985).

[3] B. Blok and M. Lublinsky, Phys. Rev. D **57**, 2676 (1998).

[4] H. Shiomi and T. Hatsuda, Nucl. Phys. **A 594**, 294 (1995).

[5] Hungchong Kim, Su Houng Lee and Makoto Oka, Phys. Lett. B **453**,199 (1999).; Hungchong Kim, Eur. Phys. Jour. **A7**, 121 (2000).

[6] Hungchong Kim, Su Houng Lee and Makoto Oka, Phys. Rev. D **60**,034007 (1999).

[7] B. L. Ioffe and A. V. Smilga, Nucl. Phys. **B 232**,109 (1984).

[8] B. L. Ioffe, Phys. At. Nucl. **58**,1408 (1995).

[9] V. A. Beilin and A. V. Radyushkin, Nucl. Phys. **B 260**, 61 (1985).

[10] P. Ball and V. M. Braun, Phys. Rev. D **49**, 2472 (1994).

[11] B. L. Ioffe, Nucl. Phys. **B188**, 317 (1981).

[12] V. M. Belyaev, V. M. Braun, A. Khodjamirian and R. Rückl, Phys. Rev. D **51**, 6177 (1995).

[13] Balitsky, V. M. Braun and A. V. Kolesnichenko, Nucl. Phys. **B 312**, 509 (1989).

[14] For example, see S. L. Zhu, W-Y. P. Hwang and Y. B. Dai, Phys. Rev. C **59**, 442 (1999).

[15] M. C. Birse and B. Krippa, Phys. Lett. B **373**, 9 (1996).

[16] M. Aw, M. K. Banerjee and H. Forkel, Phys. Letts. B **454**, 147 (1999).

[17] Hungchong Kim, Phys. Rev. C **61**,019801 (2000).

[18] B. Krippa and M. C. Birse, Phys. Rev. C **61**,019802 (2000).